U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE
SUBCOMMITTEE ON ENERGY

HEARING CHARTER

Assessing the Goals, Schedule and Costs of the Global Nuclear Energy Partnership

Thursday, April 6, 2006

1. Purpose

On Thursday, April 6, 2006, the Energy Subcommittee of the House Committee on Science will hold a hearing to examine the goals, schedules and costs of the advanced fuel cycle technologies research and development (R&D) program in the Administration's Global Nuclear Energy Partnership (GNEP) proposal.

2. Witnesses

Mr. Shane Johnson, Deputy Director for Technology, Office of Nuclear Energy Science and Technology, Department of Energy

Dr. Neil Todreas, Kepco Professor of Nuclear Engineering and Professor of Mechanical Engineering, Massachusetts Institute of Technology

Dr. Richard Garwin, IBM Fellow Emeritus, Thomas J. Watson Research Center, Yorktown Heights, NY

Mr. David Modeen, Vice President, Nuclear Power and Chief Nuclear Officer, Electric Power Research Institute

3. Overarching Questions

- Is the R&D program envisioned by GNEP likely to be an effective approach to get us to an advanced nuclear fuel cycle that minimizes waste and ensures the long-term sustainability of nuclear power?
- Are the proposed timelines for technology demonstration and deployment realistic? Do we know enough to build three major demonstration facilities in the next ten years?
- What are the cost estimates for GNEP and are they realistic?
- If GNEP were successful, how would the domestic nuclear energy landscape change?

4. Brief Overview

- Nuclear reactors generate about 20 percent of the electricity used in the U.S. No new nuclear plants have been ordered in the U.S. since 1973, but there is renewed interest in nuclear energy both because it could reduce U.S. dependence on foreign oil and because it produces no greenhouse gas emissions.

- One of the barriers to increased use of nuclear energy is concern about nuclear waste. Every nuclear power reactor produces approximately 20 tons of highly radioactive nuclear waste every year. Today, that waste is stored on-site at the nuclear reactors in water-filled cooling pools or, at some sites, after sufficient cooling, in dry casks above ground. About 50,000 metric tons of commercial spent fuel is being stored at 73 sites in 33 states. A recent report issued by the National Academy of Sciences concluded that this stored waste could be vulnerable to terrorist attacks.

- Under the current plan for long-term disposal of nuclear waste, the waste from around the country would be moved to a permanent repository at Yucca Mountain in Nevada, which is now scheduled to open around 2012. The Yucca Mountain facility continues to be a subject of controversy. But even if it opened and functioned as planned, it would have only enough space to store the nuclear waste the U.S. is expected to generate by about 2010.

- Consequently, there is growing interest in finding ways to reduce the quantity of nuclear waste. A number of other nations, most notably France and Japan, "reprocess" their nuclear waste. Reprocessing involves separating out the various components of nuclear waste so that a portion of the waste can be recycled and used again as nuclear fuel (instead of disposing of all of it). In addition to reducing the quantity of high-level nuclear waste, reprocessing makes it possible to use nuclear fuel more efficiently. With reprocessing, the same amount of nuclear fuel can generate more electricity because some components of it can be used as fuel more than once.

- Experts on nuclear energy have suggested that if the United States is to expand the use of nuclear power, it will have to develop an advanced fuel cycle that involves reprocessing spent fuel and "transmutation" of some of the most radioactive waste components in special reactors called "burner" or "fast"[1] reactors that change, or "transmute," some of the most radioactive elements into less radioactive elements.

---

[1] "burner" refers to the fact that these reactors consume (or "burn") highly radioactive spent fuel components and "fast" refers to the fact that these reactors involve high temperature (and, therefore, fast moving) neutrons. Fast neutrons can produce nuclear reactions that change, or "transmute," some highly radioactive elements into less radioactive elements.

- During last year's appropriations process, the House Appropriations Subcommittee on Energy and Water expressed the view[2, 3] that DOE must accelerate the development and demonstration of reprocessing technology to enable the development and deployment of an advanced fuel cycle for nuclear power reactors in the U.S.

- On February 6, the Administration announced the Global Nuclear Energy Partnership as part of its fiscal year 2007 (FY07) budget request. According to the Administration, the vision for GNEP is to provide for the safe and extensive expansion of nuclear power worldwide, while addressing nuclear weapons proliferation and waste management concerns. GNEP has two main components:
  1. the development of a domestic advanced nuclear fuel cycle that includes reprocessing and "transmutation" of the most highly radioactive waste components into less radioactive elements; and
  2. the establishment of an international framework for the selling and leasing of nuclear fuel and reactor technologies.

- The component of GNEP that is the subject of this hearing, the development of an advanced nuclear fuel cycle for use by the domestic commercial nuclear power industry, has the potential to significantly reduce both the volume and the radioactivity of nuclear waste produced by commercial power reactors. Successful deployment of an advanced fuel cycle could reduce nuclear waste from electricity generation to the extent that the Yucca Mountain geological waste repository would be sufficient to store most, if not all, of the waste expected to be produced by commercial power reactors during the next 100 years. Without an advanced fuel cycle, continued use of nuclear power would require the construction and licensing of several more geological waste repositories like Yucca Mountain.

- Under the GNEP, the Administration is proposing to build and operate three major new advanced fuel cycle technology demonstration facilities within ten years—
  1. a UREX+ nuclear fuel reprocessing facility (UREX+ is an advanced nuclear fuel reprocessing technology that works in the laboratory but that has not yet been tested on a sufficient scale to demonstrate its feasibility);

---

[2] The report accompanying H.R. 2419, the *Energy and Water Development Appropriations Act for Fiscal Year 2006*, which the House passed in May 2005, directed DOE to focus research in its Advanced Fuel Cycle Initiative program on improving nuclear reprocessing technologies. The report went on to state, "The Department shall accelerate this research in order to make a specific technology recommendation, not later than the end of fiscal year 2007, to the President and Congress on a particular reprocessing technology that should be implemented in the United States. In addition, the Department shall prepare an integrated spent fuel recycling plan for implementation beginning in fiscal year 2007, including recommendation of an advanced reprocessing technology and a competitive process to select one or more sites to develop integrated spent fuel recycling facilities."

[3] During floor debate on H.R. 2419, the House defeated an amendment that would have cut funding for research on reprocessing. In arguing for the amendment, its sponsor, Mr. Markey, explicitly raised the risks of weapons proliferation. Specifically, the amendment would have cut funding for reprocessing activities and interim storage programs by $15.5 million and shifted the funds to energy efficiency activities, effectively repudiating the report language. The amendment was defeated by a vote of 110-312.

2. an Advanced Burner Reactor (ABR), a specialized nuclear reactor (in this case, a sodium-cooled fast reactor) designed to "transmute" highly radioactive nuclear waste components into to less radioactive elements; and
3. an Advanced Fuel Cycle Facility (AFCF), a specialized R&D and test facility to develop and test reprocessed nuclear fuels produced by the UREX+ process to be used in the ABR.

- Questions remain as to the scale and cost of these facilities (current estimate of construction costs alone is $4 billion over ten years to build all three demonstration facilities), the reasonableness of the proposed timeline, and the fundamental R&D that still must be carried out to make these demonstrations successful.

- In particular, Energy Subcommittee Chairman Judy Biggert, in a conversation with Deputy Secretary of Energy Clay Sell last year, asked DOE to conduct a complete systems analysis the of the anticipated fuel cycle, and the R&D steps necessary to implement it. (A systems analysis involves an integrated analysis and modeling of all the components of a an advanced fuel cycle—commercial power reactors, reprocessing technologies and facilities, Advanced Burner Reactors, and waste disposal technologies and facilities—, how all of the components would interact as a system, and how technology choices related to any one component would affect other elements of the system.) In addition, Section 955 of the Energy Policy Act of 2005 requires DOE to do a survey of the civilian nuclear infrastructure and facilities in the national laboratory system. Neither of these efforts has been completed.

5. Issues

Do we know enough to build each of these three major demonstration facilities?
Science and engineering related to advanced fuel cycle technologies have not advanced much in the last 30 years because, until quite recently, it has been U.S. policy not to pursue reprocessing of spent nuclear fuel. Consequently, many fundamental questions remain in the areas of chemistry, materials and physics related to fuel recycling (reprocessing and "transmutation") and advanced waste management.

These questions can be addressed, in part, through the development of sophisticated molecular-scale computer models, but all models have to be validated empirically (both in the lab and through engineering scale demonstrations) to be useful. According to some experts, neither the computer models, nor the experiments required to validate them, have been developed to an extent sufficient to address the outstanding science and engineering questions related to advanced fuel cycle technologies. The Basic Energy Sciences Office

(BES) of the DOE Office of Science is planning the second in a series of workshops[4] on the advanced fuel cycle this coming summer. The second workshop will focus specifically on the R&D required to support GNEP. To what extent will or should the results of this workshop influence the timeline for technology demonstrations?

Are the proposed timelines for technology demonstration and deployment realistic? The proposed timeline calls for all three demonstration facilities—the UREX+ reprocessing facility, the Advanced Burner Reactor (ABR), and the Advanced Fuel Cycle Facility (AFCF) —to be built and operational in approximately the next ten years, at a total estimated construction cost of at least $4 billion. The current budget request for these activities is $250 million, meaning construction costs alone would require the budget to almost double over the next decade. There are also R&D activities that will need to be done to feed into the design and construction activities. In addition, there is another large demonstration elsewhere in the nuclear energy R&D program, the Next Generation Nuclear Plant, that is legally required to be operational by 2021 and is likely to compete for funding.

If resources are constrained, is there a logical way to sequence these activities? If an advanced fuel cycle were in commercial operation, reprocessing would precede fuel fabrication and its use in special reactors ("burner" or "fast" reactors, such as the ABR) that are necessary to recycle the fuel. But experts say that the benefits of the advanced fuel cycle are dependent on the success of the ABR, which, in turn, may first require the construction and operation of the AFCF.

Are the cost estimates for GNEP realistic? Many of the parameters of the research program and the demonstration facilities have not yet been determined, making current cost estimates unreliable. According to testimony given by Deputy Secretary of Energy Clay Sell before the Senate Appropriations Committee on March 2, the Department "will be looking for a sizeable portion of GNEP costs to be shared by [their] partners and industry starting in FY 2008." How interested is industry in cost-sharing and what level of commitment is DOE counting on?

How does the nuclear industry view GNEP?
Key players in the nuclear future, most notably industry and the Nuclear Regulatory Commission (NRC) were not at the table during the development of GNEP. Some in industry and in Congress are concerned that GNEP will distract from licensing and building new nuclear power plants and the Yucca Mountain repository in the next 5-10 years. The Electric Power Research Institute (EPRI), representing all of the nuclear-owning utilities, issued a draft "Consensus Strategy for U.S. Government and Industry" (Appendix A). In short, EPRI identifies industry priorities and R&D goals that do not seem entirely aligned or complementary to the R&D goals outlined in GNEP.

---

[4] In September 2005, the Basic Energy Sciences Office (BES) of the DOE Office of Science hosted a workshop entitled, *The Path to Sustainable Nuclear Energy: Basic and Applied Research Opportunities for Advanced Fuel Cycles*. Workshop participants identified several science and engineering challenges that must be overcome in the course of developing advanced fuel cycle technologies.

If GNEP were successful, how would the domestic nuclear energy landscape change? The U.S. government heavily subsidized the nuclear industry to get it to where it is today. Utilities building new nuclear power plants over the next several years will also have access to federal subsidies and risk insurance, but they will own, operate and safeguard the plants. There is little disagreement that an advanced fuel cycle will be much more expensive than the once-through fuel cycle currently in use. What happens if industry isn't willing to build, buy or operate any of the technologies of the advanced fuel cycle? Is the public benefit large enough that the government should pay the entire bill?

Workforce needs. One issue that several experts have brought up is that of the scientific and engineering workforce necessary for the future of nuclear power. The Administration has proposed zeroing its University support program (housed in the Nuclear Energy Office) in FY07, claiming that the goals of the program have been met in terms of the number of undergraduate students enrolled in nuclear engineering programs. There is some disagreement over which numbers are relevant. The number of students graduating from these programs, in addition to the number of masters and doctoral students, has actually declined in recent years. This does not appear to bode well for an expanded domestic nuclear industry.

6. Background

Current U.S. Practice: The open fuel cycle

Current U.S. nuclear technology uses what is called an "open fuel cycle," also known as a "once-through cycle" because the nuclear fuel only goes through the reactor one time before disposal, leaving most of the potential energy content of the fuel unused. In an open cycle, the uranium is mined and processed, enriched,[5] and packaged into fuel rods, which are then loaded into the reactor. In the reactor, some of the uranium atoms in the fuel undergo fission, or splitting, releasing energy in the form of heat, which in turn is used to generate electricity. Once the fission efficiency of the uranium fuel drops below a certain level, the fuel rods are removed from the reactor as spent fuel.

Spent fuel contains approximately 95 percent uranium by weight.[6] The remaining 5 percent consists of other radioactive elements, including plutonium, which accounts for 1

[5] The enrichment process increases the ratio of the ^{235}U isotope relative to the ^{238}U isotope. Uranium ore contains less than 1 percent ^{235}U by weight and only ^{235}U is fissionable. Low-enriched uranium for light-water reactors typically contains 3-4 percent ^{235}U.
[6] The percentage of ^{235}U in spent fuel is only slightly higher than the naturally occurring level; however, other isotopes of uranium in the spent fuel must be removed before the uranium can be re-enriched into usable fuel.

percent of the total spent fuel.[7] The radioactivity of the spent fuel means that it still generates a lot of heat, so after removal, the spent fuel rods are cooled in deep, water-filled pools. After sufficient cooling (typically 3-5 years), the fuel rods may be transferred to dry cask storage pending ultimate disposal at a geologic waste repository such as Yucca Mountain. Often they are just left in the cooling pools while awaiting disposal.

The repository at Yucca Mountain will effectively be full by the year 2010 with the spent fuel from the current fleet of reactors. As the industry looks to extend the operational lifetime of existing nuclear power plants while beginning the process of getting new plants designed and built, current waste management policies and statutes deserve to be reexamined. The options are:

- increase the statutory storage capacity of Yucca Mountain to its technical limit (approximately double the statutory limit);
- build a second repository;
- establish a plan for indefinite above-ground dry storage until another solution is found; or
- develop an advanced fuel cycle that minimizes nuclear waste such that only a single repository will be needed for the next century.

In fact, some suggest that selecting one of these options is a necessary prerequisite to any expansion of the nuclear industry in this country because the public needs to be convinced that the U.S. has a long-term strategy for waste disposal. In addition, by law, the Nuclear Regulatory Commission must make a "waste confidence determination"—that the waste created can be safely disposed of—in order to continue issuing facility licenses. The political hurdle to increasing the statutory capacity of Yucca or building a second repository seems insurmountable for the time being. A National Academy of Sciences panel determined that dry storage is a valid option from a technical and safety standpoint.[8] But the Administration is taking the position that interim storage is insufficient, and that the U.S. must lead the world toward a long-term solution. GNEP would put the U.S. on a path toward developing an advanced fuel cycle.

<u>The advanced fuel cycle as envisioned in GNEP</u>

The advanced fuel cycle requires the same mining, processing and fuel fabrication as the open cycle, at least for the current generation of nuclear reactors. However, in the advanced fuel cycle, the cooled spent fuel is reprocessed, or chemically separated into

[7] Four percent of the spent fuel consists of fission products (elements that result from splitting the Uranium—primarily Strontium, Cesium, Iodine, Technetium and elements in a series known as the Lanthanides) and transuranics (elements greater than Uranium that result from the capture of neutrons, including Plutonium, Neptunium, Americium and Curium). The fission products and transuranics have half-lives ranging from a few days to millions of years. The "half-life" of a radioactive substance is the period of time required for one-half of a given quantity of that substance (e.g. plutonium) to decay either to another isotope of the same element, or to another element altogether. The substances with shorter half-lives tend to generate more heat.

[8] *Safety and Security of Commercial Spent Nuclear Fuel Storage,* Board on Radioactive Waste Management, National Academy Press, 2005.

various combinations of its many components. In this approach, some components of the spent fuel, known as the "transuranics," can be used to fabricate fuel for a "burner" or "fast" reactor, such as the ABR. The transuranics are elements listed after uranium in the period table of the elements. Plutonium is included in this group. In theory, the transuranics could be recycled several times in fast reactors until most of the energy content is converted into electricity and the remaining material is sent to Yucca Mountain. However, there is still a waste stream associated with each of these recycles, and utilization of fast reactors, such as the ABR, as part of an advanced fuel cycle may require the development of additional reprocessing technology. Recycling the transuranics in fast reactors involves a physical process called "transmutation", which, in addition to producing electricity, reduces the radioactivity and associated heat output of the remaining spent fuel. This is significant because the repository at Yucca Mountain is technically limited by the heat content of the stored waste rather than simply the volume. If the United States is able to develop and deploy an advanced fuel cycle for commercial power reactors that includes "transmutation" of highly radioactive waste in fast reactors, such as the ABR, it may be possible to store all future commercially-generated nuclear waste in Yucca Mountain.[9, 10, 11, 12] Without an advanced fuel cycle capability, several more geological waste repositories like Yucca Mountain will be required.

Near-term GNEP technology demonstration plans

---

[9] The separated uranium is considered low-level waste and can be stored as such—that is, it does not need to be stored in a geologic repository like Yucca Mountain. While the uranium, which makes up 95 percent of the spent fuel by weight, theoretically can be treated to make it usable reactor fuel again, the technology to do so in practice does not exist and is not considered practical in the near term.

[10] Under the most likely U. S. reprocessing scenario, some of the most problematic but short-lived radioactive waste could be stored above ground in dry casks for 100 years until it decayed significantly, at which point it could either be moved to Yucca Mountain or perhaps treated further using some other technology. Some of the longer-lived material could go directly to Yucca Mountain following the separations process. Some of the shorter-lived highly radioactive material would be left in with the fuel materials, at least temporarily, to make the fuel materials more difficult to divert for weapons purposes. However, this same "protective" material may have to be separated out before a usable fuel can be fabricated.

[11] One point of controversy regarding Yucca Mountain is whether the radiation standard should be for 10,000 years or more than a million years. According the DOE's calculations, the advanced fuel cycle scenario described above could result in a hundred-fold increase in the technical capacity of the Yucca Mountain repository, as well as a reduction in the radiotoxicity of the repository waste to below the level of natural uranium ore in less than 1,000 years. A radiation level this low would eliminate that particular debate over Yucca Mountain.

[12] Several countries around the world, including Japan, Russia and France, currently reprocess their spent fuel with a process known as PUREX, short for plutonium-uranium extraction, in which plutonium and uranium streams are isolated from the remaining elements in the spent fuel. (PUREX was developed as part of the U.S. weapons program explicitly to make plutonium for nuclear weapons.) In the current commercial application of PUREX, most of the highly radioactive components are cooled and then vitrified, or encased in glass, for long-term disposal. The uranium separated through PUREX is disposed of as low-level waste. The pure plutonium can be mixed with freshly mined and enriched uranium to fabricate a mixed-oxide fuel known as MOX, which is recycled into thermal reactors to generate more power. Current practice in these countries is to reuse the plutonium only once and then dispose of the remaining spent fuel. This approach is known as partial recycle, and is far different from the advanced fuel cycle envisioned under GNEP. Fast reactors needed to consume other long-lived radioactive elements (in particular the transuranics) are not currently part of this fuel cycle, but there are plans to incorporate fast reactors in France several decades from now.

The Administration is requesting $250 million in the FY07 Nuclear Energy, Science and Technology (NE) budget to accelerate R&D and begin design work on three major advanced fuel cycle demonstration facilities: a UREX+ reprocessing facility, an advanced burner (fast) reactor, and an advanced fuel cycle facility. According to DOE, $155 million of that sum, if appropriated, will go toward design work for an engineering scale demonstration of UREX+. A preliminary timeline calls for all three facilities to be built over the next ten years or so, in anticipation of advanced fuel cycle technology initial deployment in twenty years. Much of the cost of these facilities will depend upon the scale of the facilities and the scope of the R&D. The three facilities combined are currently estimated to cost at least $4 billion just to build.

1. UREX+

UREX+ is based on the PUREX technology originally developed in the U.S. and in use today in other countries as mentioned above. In both processes, spent fuel rods are chopped up and dissolved in an acidic bath before constituent elements are chemically separated. The main differences are: 1) UREX+ does not separate a pure plutonium stream – instead it always leaves plutonium mixed with some combination of other highly radioactive elements and 2) UREX+ is a continuous rather than batch process. These differences mean that UREX+ is more proliferation-resistant than PUREX, and could have significantly less liquid radioactive waste associated with the process. In fact, DOE's conceptual goal is to recycle the liquid solvent in the process multiple times, then purify the liquid before disposal by removing the remaining radioactive elements. If this proves successful at the engineering scale, DOE would be able to mitigate concerns about a repeat of the type of environmental problems experienced at the DOE Hanford site.

Different versions of UREX+ have been demonstrated at the bench scale in batch processes—processing approximately one kilogram of spent fuel per year. DOE officials have been inconsistent in predictions of the scale of the demonstration plant, with scales under discussion ranging from hundreds of kilograms to 200 metric tons. For comparison, an industrial scale reprocessing facility might be on the order of 2000 metric tons total input capacity per year, approximately the output of the current fleet of light water reactors. Scale-up of chemical processes can involve numerous chemical engineering challenges that do not exist at the bench scale. Chemistry involving nuclear materials presents additional and unique challenges. Discovering and addressing all of these challenges is the main purpose of an engineering scale demonstration.

2. Advanced Burner Reactor

The advanced burner reactor (ABR) being proposed by DOE is, to be more precise, a sodium-cooled fast reactor. This particular design selection was made from the six technologies that were considered under DOE's Generation IV (GenIV) reactor program. The other designs are being pursued by other countries in the GenIV partnership, and domestic R&D on those designs has been all but eliminated in the FY07 budget request (with the exception of the very high temperature reactor selected under the Next Generation Nuclear Plant program). In general, GenIV reactors are designed to be more energy efficient, proliferation-resistant and safer than the current fleet of reactors. In particular, the sodium-cooled reactor design chosen for the ABR is considered by the technical community to be one of the best choices for efficient transmutation of the transuranics. Notably, not a single fast reactor has been successfully commercialized anywhere in the world. However, the U.S. and several other countries do have a long history of research on fast reactor technologies, including sodium-cooled fast reactors.

3. Advanced Fuel Cycle Facility

The advanced fuel cycle facility (AFCF) would serve the fuel design and testing needs for the ABR. The fast reactor fuels made possible by the UREX+ separations process currently exist only in concept. AFCF would be a dedicated facility for the R&D necessary to make these fuels a reality, assuming there are no as-yet-unknown technical showstoppers. Once fuels were designed and tested in the demonstration ABR, tests to characterize and understand the new spent fuel, and tests using that information to optimize the fuel, would also be done at AFCF.[13]

7. Witness Questions

Mr. Johnson

- Please describe the timelines for major Global Nuclear Energy Partnership (GNEP) demonstration projects as currently envisioned. What are the anticipated costs of each component? What is the life cycle cost of the program and what does that encompass? How and when will the Department of Energy (DOE) determine how to distribute the $250 million requested for fiscal year 2007?
- Please describe the fuel cycle systems analysis that is currently underway by DOE. What questions will this analysis answer? What is its status? To what extent will the results from this analysis influence GNEP program planning?
- What other research will be performed under GNEP?

Dr. Todreas and Dr. Garwin

- How realistic are the goals, timelines and budgets being proposed under the Global Nuclear Energy Partnership (GNEP)?
- What does the Department of Energy (DOE) need to do to develop a robust program to meet its goal of an advanced nuclear fuel cycle – one that includes

[13] A possible future GNEP technology is pyroprocessing, or electro-metallurgical reprocessing, a dry process in which fuel rods are mechanically chopped and fuel is electrically separated into constituent products. At this time, pyroprocessing appears to be the best candidate for reprocessing the spent fuel coming out of the ABR, assuming that the ABR is operated with metal fuel rather than metal-oxide fuel (e,g, uranium rather than uranium oxide). The U.S. has experience operating a small-scale pyroprocessing facility in Idaho, to reprocess the stockpiled spent fuel from the EBR-II, an experimental fast reactor shut down ten years ago. However, the nature of that stockpile is quite different from the spent fuel that the ABR would produce in the advanced fuel cycle, so much research still needs to be done on the pyroprocessing technology itself.

both recycling and transmutation - while sufficiently addressing non-proliferation and waste management needs?

- What significant research and development (R&D) questions, both science and engineering, exist for UREX+? Sodium-cooled fast reactors? Mixed-actinide fuels? In your view, how well do the GNEP R&D priorities coincide with these research needs?
- DOE is in the process of developing the tools to carry out a cradle-to-grave systems analysis of the advanced fuel cycle. What questions should that systems analysis be able to answer?

Mr. Modeen

- Please summarize the draft report, "The Nuclear Energy Development Agenda: A Consensus Strategy for U.S. Government and Industry," presented by the Electric Power Research Institute at a nuclear energy research and development summit in February. Who was involved in the development of this report and what is its status?
- What are the utility industry's nuclear research and development (R&D) priorities? How do they compare to the R&D priorities in Global Nuclear Energy Partnership (GNEP)?
- How realistic are the goals, timelines and budgets being proposed under GNEP?
- DOE officials have stated that they expect industry to cost-share in the demonstration of GNEP technologies, including reprocessing, fuel fabrication and fast reactor technologies. What does industry see as its role in GNEP technology demonstrations?

Appendix A

The Nuclear Energy Development Agenda:
A Consensus Strategy for U.S. Government and Industry

<u>Executive Summary</u>

Nuclear energy in the U.S. is entering a renaissance. With strong interest and support for new plant construction, there is a sense of a bright future not only for nuclear energy's increasing role in U.S. electricity generation and reliability, but also in helping meet the challenges of (1) revolutionizing the transportation sector's dependence on foreign oil, (2) reducing the need to use natural gas for electric power generation and for the production of hydrogen for industrial applications, (3) fostering safe and proliferation-resistant use of nuclear energy throughout the world, and (4) achieving these in an environmentally responsible manner.

Meeting these challenges with nuclear energy requires consensus, and a coordinated effort on what needs to be done. Achieving this *nuclear energy agenda* will require the combined efforts of industry and government, supported by the innovation of the research community. The Department of Energy and Congress will play a critical role in this consensus, facilitating nuclear energy's expanding role in a sustainable national energy policy.

The Electric Power Research Institute has developed a technically-based, market-relevant, and nationally-oriented assessment of the nuclear systems needed in the United States over the next half century. This assessment was supported by the technical resources of the Idaho National Laboratory. The assessment is founded on the assumption that nuclear energy will be challenged to expand dramatically in the world over the coming decades: It must provide safe, reliable and environmentally responsible electricity and process heat to meet the needs of the industrial and residential sectors. U.S. nuclear energy technology, along with realistic plans, resources and a renewed infrastructure must all be ready for this expansion. Government and industry must share and coordinate their responsibilities with a *consensus strategy* for nuclear energy.

To forecast the U.S. nuclear technology needs, moderately aggressive planning assumptions were developed to guide the types and timing of the technology needed in seven *major goals*:

1. Ensure the continued effectiveness of the operating fleet of nuclear plants
2. Establish an integrated spent fuel management system consisting of centralized interim storage, the Yucca Mountain repository, and, when necessary, a closed nuclear fuel cycle.
3. Build a new fleet of nuclear plants for electricity generation.

4. Produce hydrogen at large-scale for transportation and industry, and eventually for a hydrogen economy.
5. Apply nuclear systems to desalination and other process heat applications.
6. Greatly expand nuclear fuel resources for long term sustainability, commercializing advanced fuel cycles when market conditions demand them in the long term.
7. Strengthen the proliferation resistance and physical protection of closed nuclear fuel cycles both in the U.S. and internationally.

With these goals, a matrix of technology options to address each goal was developed with an assessment of the technology capabilities and challenges of each option. From this matrix, a technology development agenda was derived, with timing and cost estimates. The evolving role of government and industry in the agenda was also considered. Finally, current nuclear R&D programs were reviewed in relation to this assessment, and three areas were identified for action:

1. **Significant light water reactor research is needed.** Many significant needs exist for the current fleet and the new fleet, especially in areas of age-related materials degradation, fuel reliability, equipment reliability and obsolescence, plant security, cyber security, and low-level waste minimization. Also, developing a new generation of LWR fuel with much higher burnup will better utilize uranium resources, improve operating flexibility, and significantly reduce spent fuel accumulations, resulting in additional improvements in nuclear energy economics. A number of these are mid-term R&D needs whose impact would be considerable, if accelerated with government investment.

2. **Nuclear energy's role in a future hydrogen economy can begin now.** An essential consideration in reducing dependence on foreign sources of oil and natural gas is found in the fact that hydrogen is necessary today in upgrading heating oil and gasoline, and in making ammonia for fertilizers. In fact, making hydrogen today consumes 5% of all natural gas in the U.S. and demand for hydrogen is growing rapidly. This situation can be improved with a nuclear system having hydrogen production capability as soon as it can be developed. In the mid-term, nuclear-produced hydrogen can be used to exploit heavy crude from large reserves in Canada and Venezuela. Of course, in the long-term, many believe that a hydrogen economy is essential for revolutionizing transportation, in which case the demand for competitive and environmentally responsible hydrogen will greatly increase. A large-scale, economical nuclear source would hasten that future.

3. **A proliferation-resistant closed fuel cycle for the U.S. should be ready for deployment by mid-century.** Establishing a closed fuel cycle with the demonstrated ability to handle much more nuclear waste will bring added confidence in a stable fuel supply and long term spent fuel management in the U.S. in support of greatly expanding the use of nuclear energy. It will also bring the potential for establishing a nuclear fuel lease/take-back regime internationally. This would reduce the number of

countries that need to develop enrichment and reprocessing technology, a goal of the President's nuclear nonproliferation initiatives. Importantly, various advanced fuel cycle technology options provide the ability to supply sufficient nuclear fuel in the future to ensure long term energy and environmental sustainability for the U.S. and globally.

Necessary technologies include cost-effective and proliferation resistant reprocessing to separate and manage wastes, and alternate reactor concepts (e.g., fast reactors) to generate electricity as they generate additional fuel and burn the long-lived minor actinides and other constituents that are recycled. These are both critical to assuring an adequate and economic supply of fuel, reducing the spent fuel backlog, and increasing the effective capacity of Yucca Mountain many-fold in the long term. While the technology challenges and market uncertainties are many, large-scale deployment of a closed fuel cycle by government and industry could begin by mid-century.

Introduction: A New Paradigm for Public-Private Cooperation on Nuclear R&D

For many years, disagreement over the future direction of nuclear energy technology in the United States has existed, hindering progress toward the full potential of this energy source. There is general agreement among experts in government and industry that nuclear energy must expand as a major component of national energy policy. In fact, the 2001 National Energy Policy included a recommendation supporting this expansion for reasons of national security, energy security and environmental quality. The disagreements have been over how to achieve this expansion safely and economically, with differing views on goals, direction, timing, R&D priorities, and the respective roles of public and private sectors.

A recent step toward forging a consensus on the future direction of nuclear energy was undertaken by the Idaho National Laboratory in July 2004, when it assembled a "Decision-Makers Forum" in Washington DC. That forum attracted a broad spectrum of key stakeholders in the nuclear technology enterprise. Although the Forum was successful at engaging industry, national laboratories and academia, significant differences among key sectors still remain.

Using the results of this forum as a starting point, the Electric Power Research Institute (EPRI), technically supported by the Idaho National Laboratory (INL), has developed this assessment of the nuclear systems R&D needed in the United States over the next half century. The assessment is founded on the assumption that nuclear energy will be challenged to expand dramatically in the world over the coming decades. An important focus is on improved coordination and prioritization of government and industry nuclear energy R&D programs.

A series of strategic planning sessions was held to map out a common set of high-level goals and time-based planning assumptions for nuclear energy, and to then identify the R&D needed to prepare for deployment consistent with those assumptions. These assumptions were formulated to be aggressive yet achievable, and were grounded upon open market principles. Following this, R&D challenges were identified. Finally, an assessment of current nuclear R&D programs was made to identify opportunities for action.

A benefit of this joint approach is its potential to build a framework for cooperation between public and private sectors for completing the needed R&D. This framework would be based on an *80-20 paradigm,* to replace the current paradigm that, "Government only works on long term research, and industry only works on short term research." Instead, having government dedicate about 20% of its efforts to short-to-medium-term R&D, and having industry dedicate about 20% of its efforts to medium-to-longer term R&D was seen as a new way to encourage collaboration in areas of common interest, and to bridge the gaps and sustain the alignment on overall goals for nuclear energy.

Vision, Principles and Methods

The purpose of this consensus strategy is to develop an aggressive, success-oriented, yet credible and defensible R&D strategy for nuclear energy in the U.S. over the next 50+ years. The long time horizon is necessary to include the development of a closed fuel cycle. Emphasis was placed on global nuclear issues only to the extent they directly impact development in the U.S. Research programs and advances internationally were not specifically incorporated.

Recent works on nuclear energy planning were reviewed (a summary is found in Appendix A), and the session leaders agreed that the primary focus of the effort should be on national energy and security missions and imperatives, and especially on the vision and goals nuclear energy must strive toward in meeting those imperatives. While these goals have been prepared by EPRI and INL, it is important for the Department of Energy (for the government) and the Nuclear Energy Institute (for the industry) to consider the merits and credibility of these planning assumptions and goals to base new actions. National goals and priorities for nuclear energy, if supported by both industry and government, will have a substantial impact on the development of new nuclear technology. New technologies with great potential to the nation will not be brought to market if government and industry do not jointly make them a priority.

The session leaders reviewed a number of existing high level vision and mission statements for nuclear energy, and arrived at a *vision* deemed appropriate for the planning exercise:

> *Expand the use of safe and economical nuclear energy in the United States to meet future electricity demand and industrial process heat needs, foster economic growth and energy diversity, provide security and proliferation resistance, and enhance environmental stewardship.*

The session leaders also provided three *guiding principles* for the consensus strategy:

1. **Strive for a moderately aggressive yet credible technology portfolio**.
2. **Understand the importance of market forces to long-term planning.** It is recognized that each future Administration and Congress will make Federal investments in nuclear R&D only to the extent necessary to achieve national goals. However, each values the private sector's participation in that investment, and ultimately in its deployment. Thus, long-term market demand is a key factor in long-term nuclear energy investments and deployment.
3. **Align the technology portfolio with evolving nuclear energy policies and priorities.** There has been a general perception that widely divergent views on nuclear energy policy exist in the U.S. Yet a surprisingly close consensus exists on the basic priorities for technology development, as shown by a review of five key government and independent studies on the future of nuclear energy in Appendix A.

The *process* was to lay out a high level set of success-oriented planning assumptions for 2015, 2030, and 2050, covering reactor technologies, fuel cycle technologies, spent fuel management, infrastructure needs, etc. These planning assumptions were then weighed against the three guiding principles above, in terms of broad national energy, economic, safety and environmental goals, considering achievability, timing and sequencing.

Next, the minimum set of nuclear technologies that would satisfy the planning assumptions were determined. Where multiple nuclear technologies could meet the goal, factors were identified that determine which ones should be pursued and/or what the appropriate "mix" in effort or investment should be. These factors included budgetary limits on R&D, technology risk, commercial cost-competitiveness, NRC licensing risk (i.e., cost and duration of review; likelihood of success), implications to overall waste management strategies and costs, etc. Also considered were market-demand issues. For example, "Will demand for hydrogen lead or lag technology development?," and "When will uranium prices justify reprocessing?"

Finally, the length of time that each of these technologies will need to become commercially competitive to support the planning assumptions was estimated; and the R&D timeline needed for each technology was set to assure in-time licensing, demonstration, and commercialization. It is important to be realistic and objective about the time and resources needed to commercialize new technologies, factoring in technological, licensing, and funding uncertainties. In particular, the time required to prepare for and successfully complete the regulatory process was included.

Planning Assumptions

The planning assumptions proposed below are intentionally challenging, but also realistic and achievable. The predicted rapid growth is enabled by competitive economics, but is also accelerated in response to the growing societal demand to reduce the environments impacts of fossil fuels, including the risk of global climate change (by imposing limits on CO_2), which will increase demands for low- or zero-emitting sources. All three categories of low or zero-emitting technologies—nuclear energy, renewable energy, and fossil energy with carbon capture and sequestration—will face formidable challenges. Specific planning assumptions are presented in Appendix B, and are summarized below:

Currently Operating Nuclear Plants:

- All existing plants remain operational in 2015, and all have applied for and have been granted a 20 year life extension. Despite continued high safety performance and record-setting reliability, materials aging and equipment obsolescence have moderated their former profitability. Continued high performance is maintained in part by strategic, safety-focused plant management, and in part by new technology solutions, e.g., advanced monitoring and repair techniques, improved fuel performance, remedial coolant chemistry, greater reliance on advanced materials and digital controls.

- In the 2020-2030 timeframe, some plants are granted an additional 20 year life extension (i.e., to 80 years). Advanced fuel designs with higher burnup limits enable longer fuel cycles, significantly increase fuel economy, and significantly reduce the rate of spent fuel generation.

New Plants for Electricity Generation:

- Six to twelve new nuclear plants are in commercial operation by 2015, with many more under construction. 30 GWe of new nuclear electric generating capacity is on line or under construction by 2020. A cumulative total of 100 GWe of new nuclear capacity has been added by 2030. By 2050, nuclear energy is providing 35% of U.S. electricity generation by adding a cumulative total of about 400 GWe of new nuclear capacity. This number includes electricity generation from all reactor types. It also includes replacement power for a large segment of the current fleet of reactors, most of which have been retired or are close to retirement by 2050. This build-rate severely challenges U.S. industrial infrastructure.

New Plants for Process Heat:

- Based on a prototype Very High Temperature Reactor (VHTR) built and operating by 2020, about twelve VHTRs are in commercial operation by 2030, with about twelve more under construction. VHTRs are assumed to be commercially successful at 600 MWth per module (nominally four modules per plant), and with an outlet temperature around 850-900C. The VHTRs are initially dedicated to producing hydrogen for commercial and industrial use, focused primarily on rapidly expanding hydrogen demand by the oil, gas and chemical industries. They expand to a fleet of roughly 200 by 2050, still focused primarily on industrial applications, but also serving a growing market for hydrogen to power fuel cells in hybrid and plug-in hybrid vehicles. U.S.-built commercial VHTRs are also serving hydrogen demand for U.S. companies at some petrochemical facilities operating overseas.

- Commercial versions of the VHTR, without hydrogen production equipment, also begin to serve process heat needs in the petrochemical and other industries. High value-added applications above 800C are found in recovery of petroleum from oil shale and tar sands, coal gasification, and various petrochemical processes (e.g., ethylene and styrene).

- Nuclear energy begins to assume a significant role, starting in the 2020 timeframe, in support of the desalination mission for arid coastal regions of the U.S. with acute shortages of potable water. Some 16 trillion additional gallons per year will be required in the United States by 2020 for municipal and light industrial uses. This is equivalent to one quarter of the combined outflow from the Great Lakes. If desalination is viable with nuclear energy, it will likely be accomplished by equipment designed for new light water reactors, or by new reactors dedicated to desalination as are being pursued in other countries.

Spent Fuel Management and Expanding Nuclear Fuel Resources:

- Licensing of a spent fuel repository at Yucca Mountain Nevada is completed by 2015, with construction and waste acceptance into the repository and into nearby above-ground storage underway by that date. Interim storage away from reactor sites is also established at two other locations in the U.S., one east and one west of the Mississippi River.

- With a rapidly expanding nuclear energy industry and a growing inventory of spent fuel, an integrated spent fuel management plan for the U.S. emerges by 2015 that obtains bipartisan support for implementation. Key elements of the plan include expansion of the capacity of the Yucca Mountain repository, and a decision to maintain continued monitoring of the repository well in excess of 50 years (e.g., 300 years) prior to closure. The plan also includes a commitment to begin reprocessing spent fuel in a demonstration plant by about 2030, based on an active R&D program aimed at identifying cost-effective and proliferation-resistant means to recover usable reactor fuel. These technologies will also demonstrate the reduction of radiotoxicity and heat output of spent fuel, and the potential to greatly extend repository capacity. The reprocessing plan is integrated with both reactor technology and repository strategies, and offers a least-cost path for safe, long-term management of spent nuclear fuel.

- The reactor technology part of this integrated strategy develops means (e.g., fast reactors) to recycle light water reactor spent fuel in order to burn minor actinides as well as produce electricity, and later to breed additional fuel. Following a demonstration plant, built and operated with government funding in 2035, new fast reactors are deployed commercially, with government subsidy as needed for the waste burning mission. In the long term, the price of uranium increases to a level that supports breeding.

R&D Technology Matrix

A matrix was created to detail the specific technology agendas and programs. Goal areas were mapped against specific technology options, missions and capabilities. Estimates were made for when each capability is needed, how many years are needed to develop, license, and demonstrate each, and from these estimates, when R&D must start or ramp up. Key R&D needs for each technical capability were identified, along with specific challenges that needed to be addressed. Next, the matrix was used to compare the relative R&D challenges, and to consider the likelihood of success. The full R&D matrix is found in Appendix C, and is summarized below.

Goal	Technology Option	Technical Capability
1. Ensure the continued effectiveness of the operating fleet of nuclear plants	Current LWRs	1A. Managing age-related degradation
		1B. Equipment reliability and system obsolescence
		1C. Power uprates
		1D. Plant security
		1E. Grid reliability

		1F. Radiation protection
		1G. Fuel reliability
		1H. New generation LWR fuel
2. Establish an integrated spent fuel management system consisting of centralized interim storage, the Yucca Mountain repository, and, when necessary, a closed nuclear fuel cycle	Interim Storage	2A. Acceptance criteria for transportation of spent HBU fuel
	YM repository	2B. Transportation and storage of multi-purpose canisters
	Economic closed nuclear fuel cycle	2C. Proliferation-resistant reprocessing
		2D. Reactors that can burn minor actinides
3. Build a new fleet of nuclear plants for electricity generation	ALWRs	3A. Demonstration licensing process
		3B. Reduce capital costs (FOAKE)
		3C. Reduce construction time
		3D. Address shortfall in infrastructure
		3E. Reduce operating costs
4. Produce hydrogen at large scale for transportation and industry, and eventually for a hydrogen economy	LWRs	4A. Conventional electrolysis
	Commercialized VHTR – H2 only	4B. High temperature electrolysis (HTE)
		4C. Sulfur-iodine (S-I) or other chemical processes
	VHTR – cogen	4D. Cogeneration with 4B or 4C
	VHTR – all	4E. Codes and Standards development
5. Apply nuclear systems to desalination or other process heat applications	ALWRs (low T)	5A. Desalination, wood pulp, urea
	VHTR (high T)	5B. Petrochemical, coal gasification, iron reduction
6. Expand nuclear fuel resources for long term sustainability	Alternate fuel cycles and reactor concepts	6A. Closed fuel cycle with breeding (e.g., fast reactors)
7. Strengthen the proliferation-resistance and physical protection technologies of closed nuclear fuel cycles., both in the U.S. and internationally	Institutional needs	7A. Real-time materials accountability
		7B. Proliferation issues and policies
		7C. Framework for int'l fuel supply/take-back regime
	Reprocessing	7D. Closed fuel cycle with supply/take-back
		7E. Assessment methodologies and technology
		7F. Physical protection technology

Timing and Costs of the Nuclear Energy Development Agenda

The timing and costs associated with addressing the R&D challenges were roughly estimated. The timelines in Appendix B are moderately optimistic estimates of how long it will take to meet the challenges. Costs were estimated based on both U.S. and international experience.

The near term deployment goals for electricity generation, including a renewed commitment to LWR research, are the least expensive. The bulk of federal investments are envisioned to occur over the next ten years, with continued modest funding after that as necessary. Costs of federal spending on electricity generation are based on continued funding on a cost-shared basis of the NP2010 program, and projections that the private sector will deploy ALWRs for electricity generation by 2015, based on limited federal incentives, with no federal funding requirements for NP2010 after that date. Total federal costs are roughly $500M through 2015, with equal or greater cost share by industry. This does not include costs of completing Yucca Mountain, which are uncertain; nor does it include the costs of revitalizing nuclear industrial infrastructure.

Federal spending for nuclear generated hydrogen and other process heat applications are based on projections that the commercial VHTR technology can be demonstrated and will become competitive in the 2020 timeframe for industrial applications. This timeline assumes that conservative technology choices are made to maximize near term licensing and commercial deployment. Total federal costs for the nuclear hydrogen mission (exclusive of hydrogen economy infrastructure, which come later and are not projected here) are estimated at $2B through about 2020, after which VHTRs will go forward as commercial units.

The costs of establishing centralized interim storage and of completing Yucca Mountain are covered by the Nuclear Waste fund (funded by a fee paid by nuclear generating plants). Eventually, after these requirements are met, and as uranium fuel prices justify a shift from an open to a closed nuclear fuel cycle, Nuclear Waste Fund revenues, at the current fee rate of 1 mil/KWH), are assumed to defray the costs of closed fuel cycle facilities, as discussed below.

The costs of establishing a closed nuclear fuel cycle are considerably higher than reestablishing the ALWR option for electricity generation and creating a commercial VHTR option for hydrogen generation. There are a number of significant technical, cost, and institutional challenges facing reprocessing that will force the postponement of the start of prototype demonstration until about 2030, and large scale deployment until mid century. Rough costs to the federal government for the least-cost path will probably exceed $35B by 2050 and could exceed $60B by 2070, including both R&D and government-funded subsidy for a portion of the construction and operation of a large number of fast reactors and nuclear fuel reprocessing plants. These costs assume significant reliance on the private sector to construct and operate fast reactors as commercial power plants (after the technology is demonstrated and licensed, and the learning curve is ascended). These costs are highly uncertain because of the speculative nature of estimating when nominal commercial viability can be achieved for these facilities.

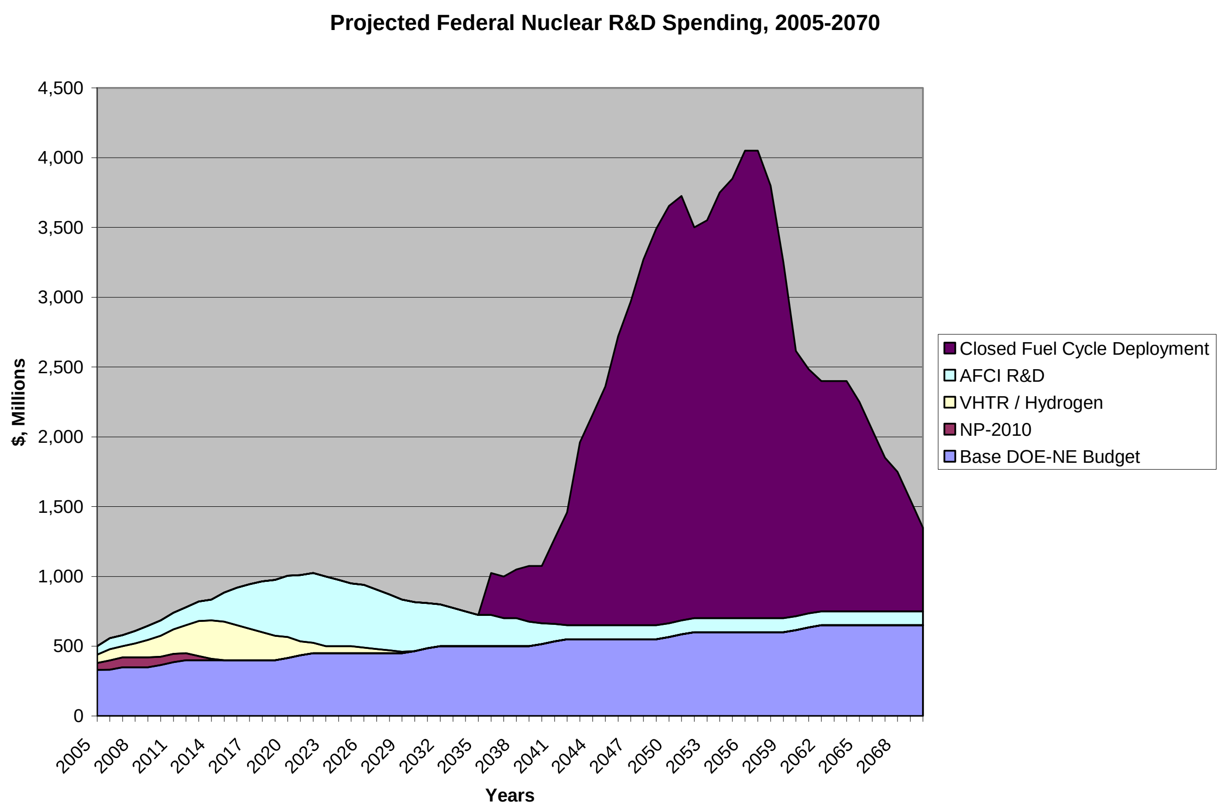
- Federally funded research for a closed nuclear fuel cycle includes major R&D to develop new separations technologies that are more proliferation resistant and less expensive than current separations processes (i.e., PUREX). R&D is also required to develop alternate fuel cycles and reactor applications (e.g., fast reactors) to generate electricity with reprocessed fuel that includes plutonium and minor actinides from ALWRs. Total RD&D costs to 2050 are estimated at roughly $15B comprising $5B for fast reactor development and demonstration and $10B for advanced separations technology.

- Federal spending to deploy closed fuel cycle technologies is estimated at roughly $20B by 2050. This estimate includes $15B for the first reprocessing plant and initial costs for a second plant beginning construction, and $5B in cumulative subsidies to construct and operate the initial modular fast reactor plants. Fast reactor subsidies would continue until cost parity with ALWRs opens the commercial market for closed cycle systems.

- Full deployment, including conversion of the nuclear generation base in the U.S. to fast reactors will take well over a century to complete.

Rough costs to the federal government through mid-century depend primarily on whether the reprocessing plan has been structured to be the least-cost path for safe, long-term management of spent nuclear fuel (per above planning assumptions), or whether an accelerated plan is chosen that does not wait for the market price for uranium to drive the shift from the once-through fuel cycle to a closed fuel cycle, and from LWRs to a mix of LWRs and fast reactors.

A rough estimate of federal investments in future nuclear R&D is shown in the figure.



There are fundamental differences between the deployment of nuclear energy generation with ALWRs and commercial VHTRs, and technologies to close the nuclear fuel cycle. First, there are commercial markets for electricity and hydrogen that enable near term deployment of ALWRs, and a transition of VHTRs to the private sector as soon as the technology is ready. There is no comparable commercial market for reprocessing. A market could evolve for the fast reactor component of closed fuel cycle systems because fast reactors can produce electricity. However, based on today's technology and uranium ore costs, fast reactors are not expected to compete with ALWRs in power generation until about mid-century. Economic parity could be achieved when new fuel for ALWRs based on enriched U-235 becomes sufficiently more expensive than fast reactor fuel using recycled components. In the long term, as uranium prices rise, the alternate fuel cycles will advance to breeding and the need for subsidy will end.

In addition, reprocessing plants are expensive and not attractive to commercial financing in the context of the U.S. economy. Thus, the cost increment for reprocessing (i.e., the incremental cost above the cost of repository disposal) will be subsidized initially by the federal government. Although the estimate above does not include repository costs, it is expected that reprocessing will remain more expensive than storage (centralized above-ground plus geologic repository) for the foreseeable future. Projections of major savings in Yucca Mountain repository costs as a result of reprocessing are highly speculative at best. On the other hand, the increased revenues to the Nuclear Waste Fund from an expanding fleet of new reactors will eventually help defray the costs of operating closed fuel cycle facilities.

It is important to note that despite the extended timetable for introducing reprocessing in the U.S. (due to R&D prerequisites to satisfy cost and nonproliferation objectives, policy considerations, etc.), that a single expanded-capacity spent fuel repository at Yucca Mountain is adequate to meet U.S. needs, and that construction of a second repository is not required under this timetable.

If, however, reprocessing is implemented on an accelerated schedule before it is economic to do so based on fuel costs, then the federal government will need to bear a much larger cost. As discussed in Appendices B and D, the optimum scenarios for transitioning nuclear energy to a closed fuel cycle in the U.S. context requires us to focus the R&D on those technologies that would enable a transition to cost-effective and proliferation resistant "full actinide recycle" mode with fast reactors that would eventually replace light water reactors. This path is preferred over one that maintains for decades a "thermal recycle" mode using MOX fuel in light water reactors, because the high costs and extra waste streams associated with this latter path do not provide commensurate benefits in terms of either non-proliferation or spent fuel management costs.

Assessment of Current Programs

Current federal programs in three major nuclear energy R&D areas were reviewed in relation to the development agenda.

Light Water Reactor R&D

Many significant needs exist for the current fleet and the new fleet, especially in areas of age-related materials degradation, fuel reliability, equipment reliability and obsolescence, plant security, cyber security, and low-level waste minimization. Also, developing a new generation of high reliability LWR fuel with much higher burnup will better utilize uranium resources, improve operating flexibility, and significantly reduce spent fuel accumulations, resulting in additional improvements in nuclear energy economics. A number of these are mid-term R&D needs whose impact would be considerable if accelerated with government investment.

Process Heat R&D

An essential consideration in reducing dependence on foreign sources of oil and natural gas is found in the fact that hydrogen is necessary today in upgrading heating oil and gasoline, and in making ammonia for fertilizers. In fact, making hydrogen today consumes 5% of all natural gas in the U.S and demand for hydrogen is growing rapidly. This situation can be improved with a nuclear system having hydrogen production capability as soon as it can be developed. In the mid-term, nuclear-produced hydrogen can be used to exploit heavy crude from large reserves in Canada and Venezuela. Of course, in the long-term, many believe that a hydrogen economy is essential for revolutionizing transportation, in which case the demand for competitive and environmentally responsible hydrogen will greatly increase. A large-scale, economical nuclear source would hasten that future.

Closed Fuel Cycle R&D

Establishing a closed fuel cycle with the demonstrated ability to handle much more nuclear waste will bring added confidence in a stable fuel supply and long term spent fuel management in the U.S. in support of greatly expanding the use of nuclear energy. It will also bring the potential for establishing a nuclear fuel lease/take-back regime internationally. This would reduce the number of countries that need to develop enrichment and reprocessing technology, a goal of the President's nuclear nonproliferation initiatives. Importantly, various advanced fuel cycle technology options provide the ability to supply sufficient nuclear fuel in the future to ensure long term energy and environmental sustainability for the U.S. and globally.

Necessary technologies include cost-effective and proliferation resistant reprocessing to separate and manage wastes, and alternate reactor concepts (e.g., fast reactors) to generate electricity as they generate additional fuel and burn the long-lived minor actinides and other constituents that are recycled. These are both critical to assuring an adequate and economic supply of fuel, reducing the spent fuel backlog, and increasing the effective capacity of Yucca Mountain many-fold in the long term. While the technology challenges and market uncertainties are many, large-scale deployment of a closed fuel cycle by government and industry could begin by mid-century.

Conclusions

- The strategy for nuclear energy development and implementation in the United States requires a consensus of industry and government.

- The overall strategy should be determined by a combination of market needs and long term nationally established energy goals for energy security, national security, and environmental quality.

- The priorities in the consensus nuclear energy strategy should address near-term, medium-term, and long term priorities. R&D needs to proceed now on all fronts, but priorities for implementation and deployment are as follows:

  - Near term: license renewal for the current fleet, and licensing and deployment of new, standardized ALWRs within the next decade. Near-term deployment of ALWRs will require demonstration of a workable licensing process, and completion of first-of-a-kind engineering for at least two standardized designs. Industry and DOE should cost share these R&D programs.

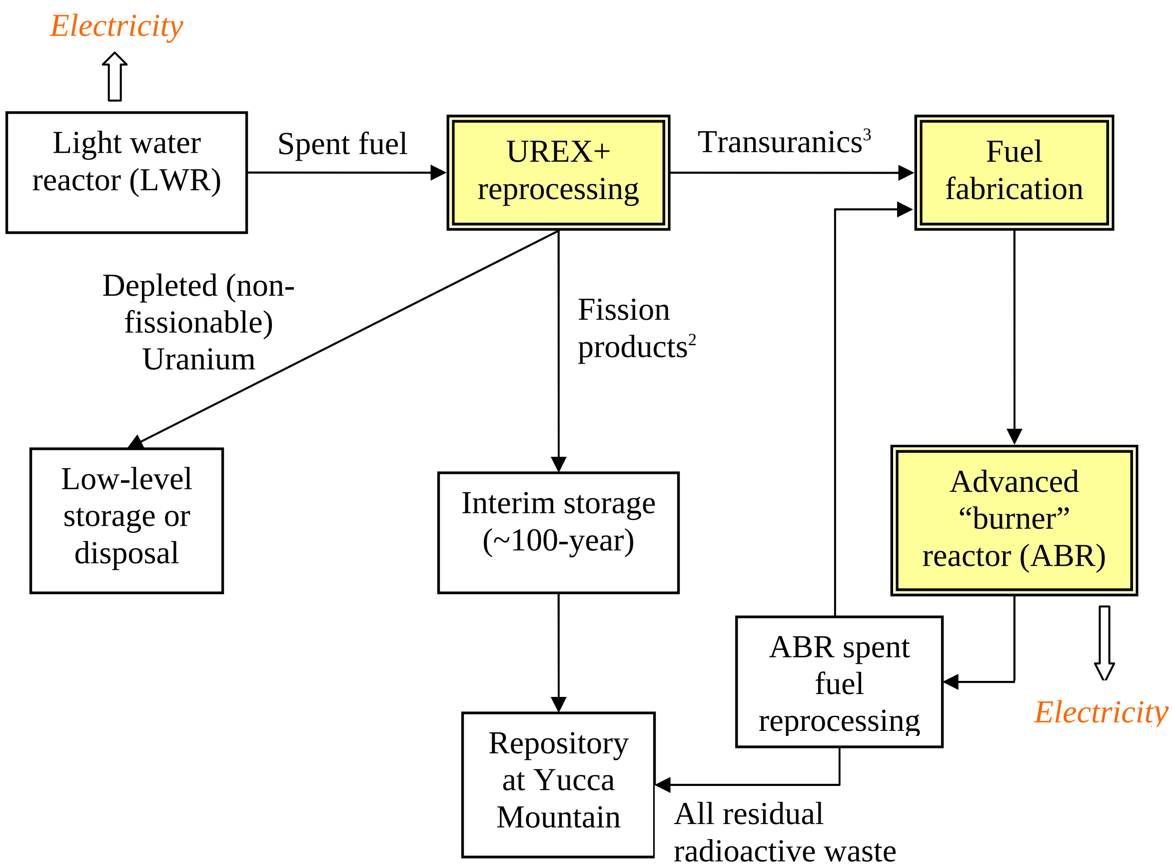
    To enable the resurgence of nuclear energy, the near term elements of an integrated spent fuel management plan must proceed with bipartisan support from both the Administration and Congress. These near term elements include completion of the repository at Yucca Mountain, deployment of multi-purpose canisters approved by the NRC, implementation of an effective spent fuel transportation system, and provision for centralized interim storage. This effort should be funded by the Nuclear Waste Fund, established by Congress and paid for by nuclear energy ratepayers and nuclear plant licensees for these purposes, in accordance with the Fund provisions in the Nuclear Waste Policy Act.

  - Medium-term: development of a high temperature commercial VHTR capable of generating hydrogen and electricity at competitive costs, for initial use by the petroleum and chemical industries. Deployment will require concept development, defining end-user requirements and interfaces, engineering, resolution of design and licensing issues and prototype demonstration. This effort should be funded by government, but targeted for rapid commercialization.

  - Long-term: development of new closed fuel cycle technologies supporting an integrated, cost-effective spent fuel management plan. Key elements of the plan include expansion of the capacity of the Yucca Mountain repository, and a decision to maintain continued monitoring of the repository well in excess of 50 years prior to closure. The plan also includes provisions for centralized interim storage of spent fuel, and a commitment to begin reprocessing spent fuel in a demonstration plant by about 2030, based on an active R&D program aimed at identifying more cost-effective and proliferation-resistant means to recover usable reactor fuel. It also includes development of safe and cost-effective fast-spectrum reactor technology for "burning" the long-lived actinides in spent fuel, and "recycling" the usable uranium and plutonium recovered from spent fuel. These capabilities, along with other advanced fuel cycle options, should be used to achieve long-term energy supply sustainability – long after fossil fuel supplies are exhausted. These facilities should be funded by government. They are not authorized expenses to be recovered from the Nuclear Waste Fund, but eventually, as uranium fuel prices justify a shift from an open to a closed nuclear fuel cycle, Nuclear Waste Fund revenues are assumed to defray the costs of closed fuel cycle facilities.

- A strategy for rebuilding the nuclear industrial infrastructure in the U.S. is necessary. Currently, major equipment must be procured offshore. Long term energy security requires that the U.S. industry have the capability of supplying and supporting U.S. energy producers, and better integrating energy supplier and end-user needs. These infrastructure needs include large numbers of new skilled construction workers, engineers, nuclear plant operators and other key personnel needed for construction, operation and maintenance of new facilities.

APPENDIX B
SIMPLIFIED[1] MATERIALS PATHWAYS IN
THE ADVANCED FUEL CYCLE



1 – A complete flow diagram would have a few more boxes and arrows, but this simplified version shows the major elements of an advanced fuel cycle under discussion in this hearing ((in double-bordered boxes)): a UREX+ reprocessing facility, a fuel fabrication facility (the "advanced fuel cycle facility" in the GNEP R&D proposal), and a fast, or "burner" reactor (ABR) for the transuranics-based fuel. In any fuel cycle, a permanent repository is required.

2 – The fission products, which result from the splitting of uranium into smaller elements, include cesium (Cs), strontium (Sr), iodine (I) and technetium (Tc), as well as a group of elements known as the Lanthanides. The Cs and Sr are short-lived and would be placed in interim above-ground storage until they are sufficiently "cool" to move into Yucca Mountain. Iodine would be removed as an off-gas during the UREX process, and Tc and the Lanthanides would likely go straight to Yucca Mountain in appropriate storage form.

3 – The transuranics are a group of elements listed after uranium in the period table of the elements and result from the capture of neutrons by uranium. They include plutonium (Pu), which accounts for one percent of the total spent fuel, as well as americium (Am), curium (Cm) and neptunium (Np).

4 – The technology for ABR spent fuel reprocessing will be dictated by the fuel choice for the ABR – a longer-term decision based on R&D carried out in the advanced fuel cycle facility.